



Technology Readiness Assessments (TRAs)

**Multi-Dimensional Assessment of Technology Maturity
Workshop
May 11, 2006**

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Outline

- **Introduction**
- **Overview of Technology Considerations During Systems Acquisition**
- **The TRA Process**
 - Identifying Critical Technology Elements (CTEs)
 - Assessing CTE Readiness
- **Technology Maturation**
- **References and Resources**

How TRAs Got Started

- “Program managers’ ability to reject immature technologies is hampered by (1) untradable requirements that force acceptance of technologies despite their immaturity and (2) reliance on tools that fail to alert the managers of the high risks that would prompt such a rejection.” *GAO/NSIAD-99-162*
- “Identify each case in which a major defense acquisition program entered system development and demonstration ... into which key technology has been incorporated that does not meet the technology maturity requirement ... and provide a justification for why such key technology was incorporated and identify any determination of technological maturity with which the Deputy Under Secretary of Defense for Science and Technology did not concur and explain how the issue has been resolved.” *National Defense Authorization Act for Fiscal Year 2002*
- “The management and mitigation of technology risk, which allows less costly and less time-consuming systems development, is a crucial part of overall program management and is especially relevant to meeting cost and schedule goals. Objective assessment of technology maturity and risk shall be a routine aspect of DoD acquisition.” *DoDI 5000.2, paragraph 3.7.2.2*



Stop launching programs before technologies are mature

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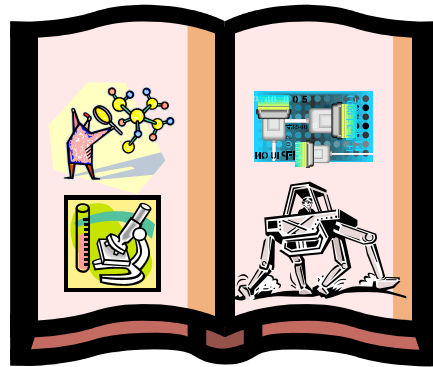
The first bullet is from a 1999 GAO study. The TRA, which is a scientific report about technology, can't really do very much about the first point –untradable requirements– since that gets into the interactions between the requirements process and the acquisition process. But the TRA is a tool that if used properly will alert managers to potential problems down the road. The GAO report also referred to TRLs pioneered by NASA.

The second bullet was a Congressional reaction to the GAO study. An annual report was called for.

To ensure that there was data for the annual report, and of course to do the right thing, the acquisition regulations were changed with the bottom line message. Don't start programs when the technology is not ready.

What is a TRA?

- Systematic, metrics-based process that assesses the maturity of Critical Technology Elements (CTEs)
 - Uses Technology Readiness Levels (TRLs) as the metric
- Regulatory information requirement for **all** acquisition programs
 - Submitted to DUSD(S&T) for ACAT ID and IAM programs



- ≠ Not a risk assessment
- ≠ Not a design review
- ≠ Does not address system integration

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CTEs will be defined in the next slide. TRLs will be described later in the briefing. ACAT ID and ACAT IAM are the large defense programs.

While this slide states what a TRA is NOT, the TRA does contribute to all of these.

Critical Technology Element (CTE) Defined

A technology element is “critical” if the system being acquired depends on this technology element to meet operational requirements with acceptable development cost and schedule and with acceptable production and operation costs and if the technology element or its application is either new or novel.

Said another way, an element that is new or novel or being used in a new or novel way is critical if it is necessary to achieve the successful development of a system, its acquisition or its operational utility.

CTEs may be hardware, software, manufacturing, or life cycle related at the subsystem or component level

This is the definition in the TRA Deskbook. Key points:

- The technology does not have to enable a key performance parameter. Any operational requirement is OK.
- The technology has to be affordable over the life cycle of the system.
- Finally, the technology must be new or novel. This does not imply the first time it is ever used. Use in a new environment is sufficient. This will be discussed in more detail later.

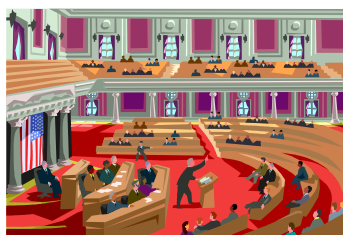
Although CTEs may be hardware, software, manufacturing, or life cycle related, one type is not treated differently than another type. They are all important. The only thing that varies is what data you look for when assessing maturity.

There has not been a lot of attention paid to life cycle related CTEs as of yet. Only know of two examples: diagnostics/prognostics on the F18 and autonomous material handling equipment (an artificially intelligent forklift) on the CVN 21. More attention is needed. Because the problem is real.

Suitability is defined as the degree to which a system can be placed and sustained satisfactorily in field use with consideration given to availability, compatibility, transportability, interoperability, reliability, wartime usage rates, maintainability, ESOH, human factors, habitability, manpower, logistics, supportability, logistics supportability, natural environmental effects and impacts, documentation and training requirements. David Duma, principal deputy director in OT&E, has compiled the following statistics. From 1985-95 67% of programs passed OT&E for suitability; from 1995 – 1999 76% of programs passed; and from 2000-2005 only 55% passed.

Why is a TRA Important? (1 of 2)

- **The Milestone Decision Authority (MDA) uses the information to support a decision to initiate a program**
 - Trying to apply immature technologies has led to technical, schedule, and cost problems during systems acquisition
 - TRA established as a control to ensure that critical technologies are mature, based on what has been accomplished



- **Congressional interest**
 - MDA must certify to Congress that the technology in programs has been demonstrated in a relevant environment at program initiation
 - MDA must justify any waivers for national security to Congress

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This is a quote from the testimony of the Honorable Ken Krieg, Undersecretary of Defense (Acquisition, Technology, & Logistics) at a September 27, 2005 Senate Armed Services Committee - "Technology maturity is a factor in reducing program risk, thereby reducing near and long-term program costs. We implemented Technology Maturity assessments to assess if acquisition programs require more mature technology before entering the next phase. In addition, we have increased the number of demonstrations and prototypes, further ensuring adequate technology maturity and military utility by 'trying before buying.'" - Note that the words 'trying before buying' paraphrase the Packard Commission recommendation to 'fly before you buy.'

Certification required per Section 801 of the FY 2006 Defense Authorization Act. Section is entitled – requirement for certification before major defense acquisition program may proceed to Milestone B. Other things must be certified as well – e.g., affordability, AoA completed, high likelihood of accomplishing its mission, ...

Quantifying the Effects of Immature Technologies

According to a GAO review of 54 DoD programs:

- Only 15% of programs began SDD with mature technology (TRL 7)
 - Programs that started with mature technologies averaged 9% cost growth and a 7 month schedule delay
 - Programs that did not have mature technologies averaged 41% cost growth and a 13 month schedule delay
- At critical design review, 42% of programs demonstrated design stability (90% drawings releasable)
 - Design stability not achievable with immature technologies
 - Programs with stable designs at CDR averaged 6% cost growth
 - Programs without stable designs at CDR averaged 46% cost growth and a 29 month schedule delay



Source: Defense Acquisitions: Assessments of Selected Major Weapon Programs, GAO-05-301, March 2005 ⁷

This GAO study was conducted to show the effects of moving forward in a program without having requisite knowledge at key decision points. The SDD decision point marks program initiation. The CDR decision point initiates building a prototype or an engineering design model.

These data demonstrate the effects of starting programs with immature technology. The top part of the chart deals with technology maturity directly. The bottom part of the chart on design stability is also applicable because immature technologies inhibit design stability.

Both MDAP and MAIS programs were included in the data. Schedule delays were measured on the basis of Initial Operating Capability (IOC) date.

Some might say that things other than technology immaturity led to the above cost and schedule growth and that GAO did not look at that. That is correct. However there is no clear causality between immature technologies and inaccurate cost estimation, there is no clear causality between immature technologies and requirement creep, ... The correlation is unarguable.

Why is a TRA Important? (2 of 2)

- The PM uses the expertise of the assessment team and the rigor and discipline of the process to allow for:
 - Early, in depth review of the conceptual product baseline
 - Periodic in-depth reviews of maturation events
 - Highlighting *(and in some cases discover)* critical technologies and other potential technology risk areas that require management attention (and possibly additional resources)
- The PM, PEO, and CAE use the results of the assessment to:
 - Optimize the acquisition strategy and thereby increase the probability of a successful outcome
 - Determine capabilities to be developed in the next increment
 - Focus technology investment



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In building the Deskbook, we interviewed a number of program managers. This represents a summation of the comments that we received.

We recommend, as a best practice, that every CTE be included in the program's risk data base. In that way, it's status will be reviewed at each systems engineering technical review. If a technology is already included in the risk data base, verification by an independent, well respected panel of experts is important. If the technology was not included in the risk data base, then its inclusion (and subsequent management actions) can potentially prevent major problems down the line.

The second bullet reinforces the point made about immature technologies. They should be deferred to the next increment of the program unless there are exceptional overriding circumstances.

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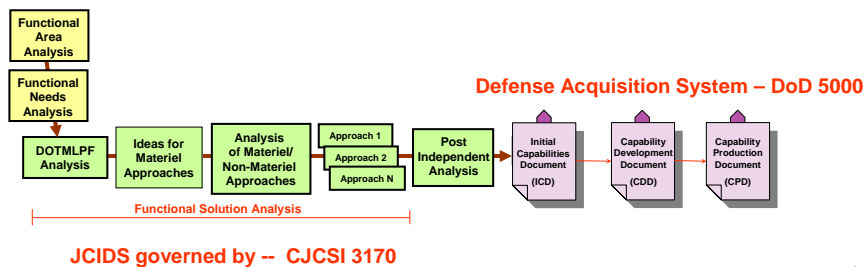
This portion of the briefing will focus on the interfaces among the systems acquisition process, the systems engineering process, and the technology development process.

Joint Capabilities Integration and Development System (JCIDS)

Strategic Guidance --
National Security Strategy/National Defense Strategy/National Military Strategy

Family of Joint Future Concepts
Concepts of Operations
Joint Tasks

Integrated Architectures



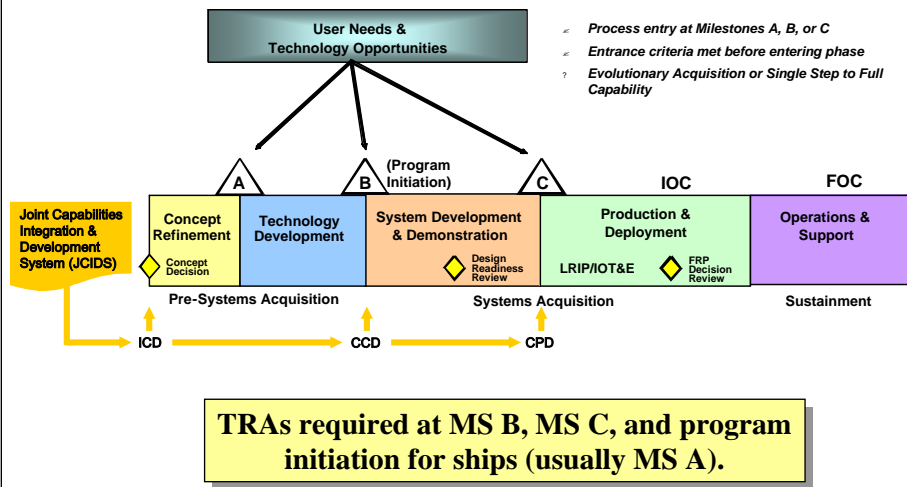
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JCIDS is a capabilities-based approach to identifying current and future gaps. It is based on top-down analyses. The Functional Area Analysis identifies the operational tasks to accomplish military objectives. The Functional Needs Analysis assesses the ability of the current and programmed capabilities to accomplish the Functional Area Analysis identified tasks. The result is a list of capability gaps. The Functional Solutions Analysis performs an operational based assessment of potential DOTMLPF (doctrine, organization, training, materiel, leadership, personnel, and facilities) approaches to solving one or more of the existing capability gaps. Not much weeding out is done in the Post-Independent Analysis unless an approach is drastically not feasible.

The final three boxes in this chart depict the interfaces with the Defense Acquisition System. The ICD is used to support concept refinement decision and Milestone A decisions and to guide the Concept Refinement and the Technology Development phases of the acquisition system. The CDD supports a Milestone B decision by providing more detail on the materiel solution to provide the capability previously described in the ICD. The CPD is used to support the Milestone C decision before a program enters Low Rate Production and Operational Test and Evaluation.

This is a militarily dominated process with minimal interfaces with the acquisition community. No one in the technology community interfaces in the Functional Solutions Analysis. Early cost/performance trades are not supported hence the GAO conclusion that “Program managers’ ability to reject immature technologies is hampered by untradable requirements that force acceptance of technologies despite their immaturity.”

Overview of Technology Considerations During Systems Acquisition



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This slide portrays more completely where the JCIDS' ICD, CDD, and CPD interface with the acquisition process. The five stages of the acquisition process are pictured. In this briefing, we will pay most attention to the first three phases since that is where the bulk of the technology considerations occur.

Say a few words about each phase. Emphasize program initiation at Milestone B. Technology maturation prior to program initiation has been identified by GAO as a commercial best practice. It also supports the concept of evolutionary acquisition. If the technology is immature, it should become the basis for future increments of the system.

TRAs are required at Milestone B, Milestone C and program initiation for ships which is normally at Milestone A.

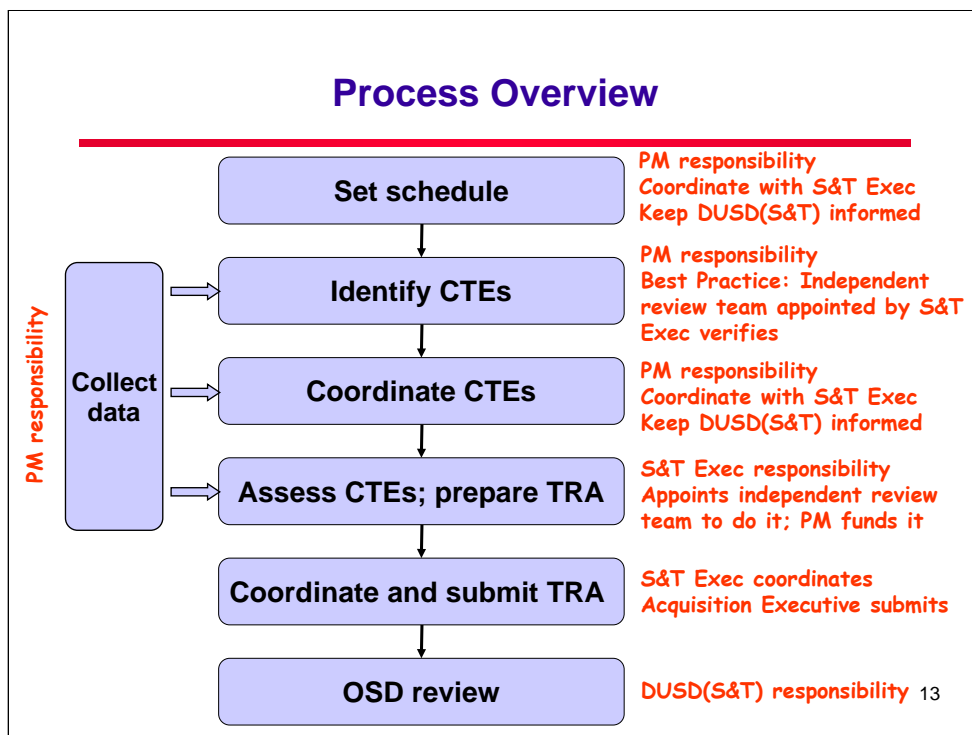
The idea, and the value and benefits, of conducting TRAs at Milestone A for other programs are currently being researched.

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We include some specific do's and don'ts in this section as well as describe the type of report that DUSD(S&T) expects.



Note that the process depicted on this slide was discussed in the three slides that depicted technology considerations during the phases of the acquisition process. On this slide, responsibilities are further clarified.

PM not responsible for performing the TRA. He helps identify the critical technologies and supports the assessment.

If backup slide is NOT being used, mention that the schedule should be integrated into the Program's Integrated Master Schedule (IMS). This point is made explicitly on the backup slide.

The following two sections of the briefing deal with the blocks of this slide in detail. Top 3 blocks + collect data are discussed in the CTE identification section. Bottom three blocks are discussed in the CTE assessment section.

Independent review team mentioned twice on this slide. We are talking about the same group of people. The second time that it is mentioned, by assess CTEs, it is a requirement. The first time it is mentioned by identify CTEs, it is a best practice which we strongly recommend.

Component S&T Executives



- **Army**
 - Deputy Assistant Secretary (Research and Technology)

Navy

- Chief of Naval Research

- **Air Force**
 - Deputy Assistant Secretary (Science and Engineering)



- **DISA**
 - Chief Technology Officer

- **DLA**
 - Chief Information Officer

- **NSA**
 - Office of Corporate Assessments



Responsible for directing the TRA

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Pictures are of:

Left side: Edmond Halley (above), Michael Faraday (below)

Right side: Leonardo da Vinci (above), Alfred Nobel (below)

Agencies need to identify who will perform the S&T Executive role; often done by the CIO since many of the programs are information technology related.

Component
S&T Executive
Appoints; PM
Funds

Independent Review Team

- **Selected from pool of recognized experts**
 - DoD Components
 - FFRDCs
 - Universities
 - Government agencies
 - Industry
 - National Laboratories
- **Final Team membership based on work breakdown structure where CTEs are located**

WBS Elements	
Manufacturing	R&M
Sensors	Crew systems
Missile warning	Antennas
Communications	Structures
Architecture	Propulsion
Processing	Electrical systems
Survivability	Materials
Software	Security
Information systems	Navigation
Training	Safety
Logistics	...



Responsible for performing and preparing the TRA

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Pictures are of Galileo Galilei, Ben Franklin, Nicolas Copernicus, Isaac Newton (left to right)

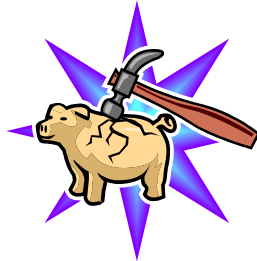
Criteria for review team membership:

- Real technology expertise as a function of the system and its WBS
- Knowledge of DoD acquisition
- Independent of program (NOT PM's CONTRACTOR)

ODUSD(S&T) may suggest that someone be included on the Team. It is a good idea to accommodate such a request.

Program Responsible for Scheduling and Funding the TRA

- **Establish / determine contract vehicle for funding**
 - CTE identification
 - Data gathering
 - Independent Review Team
 - Training and preparation
 - Assessments
 - Report
 - Travel
 - Development of Technology Maturation Plans
- **Integrate TRA plan of attack and milestones into the Integrated Master Schedule**



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Much of the funding is for the independent review team – they are the ones doing the assessment

Best practice is to have a CLIN in the contract of the program office's contractors to support the TRA

PM
Responsible;
Ind Review Team
Verifies

CTE Identification: Management Process

- **Initial review**

- PM led with program office, system contractors, and Govt labs
- Thorough, disciplined and conservative approach
- Identifies longer list of candidates to ensure that no potential CTE is overlooked
- Identifies information needed to determine whether the candidates meet the criteria in the CTE definition



- **Independent review**

- Conducted by independent review team of experts
- Resolves status based on data and expertise
- Makes recommendations whether candidates meet the criteria

We distinguish a CTE identification management process from a technical process. The need for an initial review by the program office and the use of an independent review team are part of the management process. The details of what they do, is the technical process which is described on the next three slides.

This slide presents a series of best practices.

As the program office goes through the possibilities, perhaps 100 CTE candidates may be identified. As data are gathered and the criteria are applied in the technical process, most of the CTE candidates will be eliminated.

There is a backup slide on the independent review team. These are the points made on the backup slide, to be made here if that slide is not used.

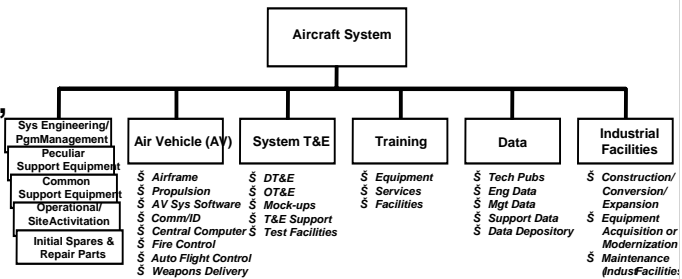
1. Component S&T Executive appoints the independent review team
2. Criteria for review team membership: real technology expertise; knowledge of DoD acquisition; independent of program (NOT PM'S CONTRACTOR)
3. ODUSD(S&T) may suggest that someone be included on the Team. It is a good idea to accommodate such a request.

There have been instances where the independent review team has added CTEs that were not suggested.

PM
Responsible;
Ind Review Team
Verifies

CTE Identification: Technical Process (1 of 3)

- Utilize the work breakdown structure (WBS), or system architecture for IT systems, to identify CTE candidates by:



Adapted from MIL-HDBK-881

- Establishing the functions to be performed by each system, subsystem, or component throughout the WBS
- Determining how the functions will be accomplished
- Identifying the technologies needed to perform those functions at the desired level

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Need to think about:

- What is the implementation of the function
- How it will be accomplished based on WBS
- What technologies become associated with the WBS elements

PM
Responsible;
Ind Review Team
Verifies

CTE Identification: Technical Process (2 of 3)

At least one answer
must be "yes"

- **Criticality to the program criteria**
 - Does the technology directly impact an operational requirement?
 - Does the technology have a significant impact on an improved delivery schedule?
 - Does the technology have a significant impact on the affordability of the system?



[Aircraft
example](#)

[Networked
communication
system example](#)

[Manufacturing
example](#)

See section D.4 of the Deskbook for other examples

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The CTE does not have to relate to a Key Performance Parameter.

While the majority of the questions on this slide and the following few slides have a "yes" or "no" answer, the expectation is the people who are involved in CTE identification will also have an explanation of their answers. In some cases, long discussions may ensue about why an answer is "yes" or "no." These discussions help avoid the misidentification of a CTE – either mistakenly classifying something as a CTE or failing to identify a CTE.

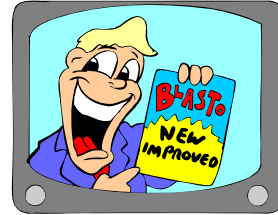
Hyperlinks are to example questions to uncover more details in the CTE identification process.

PM
Responsible;
Ind Review Team
Verifies

CTE Identification: Technical Process (3 of 3)

- **New or novel criteria**
 - Is the technology new or novel?
 - Is the technology modified?
 - Has the technology been repackaged such that a new relevant environment is realized?
 - Is the technology expected to operate in an environment and/or achieve a performance beyond its original design intention or demonstrated capability?

At least one answer
must be "yes"

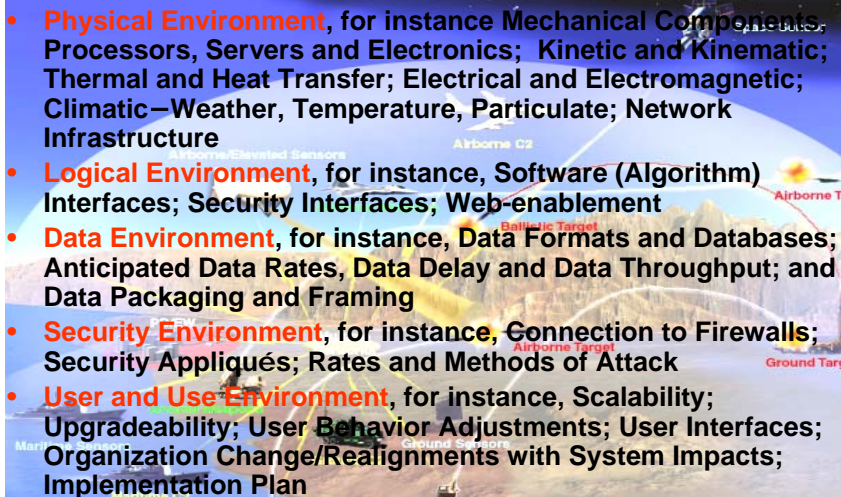


Environment key to "new or novel"

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So now we have established that the CTE candidate is important. "New or novel" is often a sticking point. For MS B, the CTE subsystem must be demonstrated in a relevant environment. How you define environment is important.

Environment Examples

- 
- **Physical Environment**, for instance Mechanical Components; Processors, Servers and Electronics; Kinetic and Kinematic; Thermal and Heat Transfer; Electrical and Electromagnetic; Climatic—Weather, Temperature, Particulate; Network Infrastructure
 - **Logical Environment**, for instance, Software (Algorithm) Interfaces; Security Interfaces; Web-enablement
 - **Data Environment**, for instance, Data Formats and Databases; Anticipated Data Rates, Data Delay and Data Throughput; and Data Packaging and Framing
 - **Security Environment**, for instance, Connection to Firewalls; Security Appliqués; Rates and Methods of Attack
 - **User and Use Environment**, for instance, Scalability; Upgradeability; User Behavior Adjustments; User Interfaces; Organization Change/Realignments with System Impacts; Implementation Plan

Others may be relevant

The environment where the technology has been used must be relevant to the application of technology in the system under consideration. A radio known to work in a pristine electromagnetic environment, would be new or novel in another environment.

User and use environment: Need to understand who the users are and whether the technology will be scalable. Doing effective change management is key.

Sample Questions to Determine if Environment is New or Novel

- Is the physical/logical/data environment in which this CTE has been demonstrated similar to the intended environment? How is it different? Is the difference important?
- Is the CTE going to be operating at or outside of the usual performance envelope? Do specifications address the behavior of the CTE under these conditions? What is unique or different about the proposed operations environment?
- Do test data, reports or analysis that compare the demonstrated environment to the intended environment exist? If modeling and simulation is an important aspect of that comparison, are the analysis techniques common and generally accepted?



See Section D.3.2 of the Deskbook for more questions

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It is important to have test data, reports of other facts to determine if test environment is relevant.

If COTS is being used in an environment other than the military environment, then more is needed. The technology should be considered new or novel.

For example, the Sergeant York was a program that attempted to develop a ground based air defense gun system. It was to be a quick program using adaptations of existing equipment, especially the fire control radar from the F-16. However, using the radar on a ground vehicle against low flying aircraft turned out to be a non-trivial problem. After several years and a large investment, the program was abandoned.

How Many CTEs Should Be Identified?

- **Don't miss any**
 - System performance, program schedule and cost could be jeopardized
- **Don't be overly conservative**
 - If too many non critical technologies are treated as CTEs, energy and resources may be diverted from the few technologies that require and intensive maturation effort



If a disciplined process leads to an inordinate number of CTEs, the proposed development program may be too far reaching



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It is really a balancing act. There is no arbitrary number. It is important not to miss any.

If a program has 100 CTEs, then it is probably too far reaching. The MDA may view this as a metric on risk.

Disaggregate CTEs Where Appropriate

Software Intensive System Example



- Conducted a thorough analysis to identify CTEs
- CTEs included
 - .Net Framework Microsoft programming model and integral Windows runtime component for building XML Web services and applications consisting of the Common Language Runtime (CLR) and a unified set of class libraries
 - COM Callable Wrappers A wrapper around a .NET object that is automatically generated by the .NET Framework CLR
 - Runtime Callable Wrappers A wrapper around (proxy for) a COM object that is automatically generated by the .NET Framework Common Language Runtime
- Could have identified a single CTE encompassing the three tightly coupled ones
- Maintained disaggregation since each is new or novel and critical to the functionality

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It would not have been appropriate to combine the three into one CTE.

CTEs May Not Be Glamorous



Ship Example

- A highly maneuverable load carrying vehicle capable of motion in any direction was identified as a CTE
 - Intended for both manual and autonomous use
- Sensors and software for autonomous travel will be new *as well as its use within the sea environment*
- This critical technology provides significant capability enhancement over existing material handling equipment and supports the reduced manning goal of the ship program



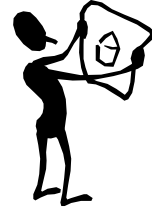
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The CTE doesn't have to be "the death ray from Mars." This technology reduces manning on the ship; it is a life cycle related CTE. It was new in that it had never been done in the at sea environment.

CTE Identification Process

Without Designs/Performance Criteria (1 of 2)

- **Situation:** Milestone B date is scheduled prior to a full definition of technology-based components, systems, or subsystems
 - Contrary to DoDI 5000.2
 - SDD entrance criteria not met—mature technology to meet approved requirements not established
 - Contrary to good systems engineering practice
 - Program should be event-driven, not schedule-driven
 - Exit criteria for the Systems Requirements Review not met—consistency among system requirements, the preferred system solution, and available technologies has not been achieved



Best practice is for the PM to recommend that the Component Acquisition Executive defer Milestone B until the program is ready

This situation is not necessarily one of immature technologies. Without a design, it is not possible to do a good job in determining the CTEs.

There is often a great deal of pressure to achieve formal program initiation on schedule because it is more difficult to maintain an adequate funding profile before program initiation. Frequently, this leads to a MS B request before the program has met the entrance criteria for SDD despite the probable effects of premature program initiation on cost and schedule. The event driven technology development process does not work well in a schedule driven world.

The best practice is to defer MS B until the program is ready and self discipline by the programs is the best way to accomplish this. The issue should be surfaced by the PM to the acquisition executive for a decision.

If the technologies are not clear or too immature, the job of the independent review team making the TRL assessments is to inform the PM and the Component S&T Executive of the situation, potentially indicating that program initiation should be deferred. The Milestone Decision Authority, however, can decide to press on. Such a risky action would be documented in the annual report to Congress.

CTE Identification Process Without Designs/Performance Criteria (2 of 2)

- If overriding circumstances exist and Milestone B is held prematurely, *the Component S&T Executive should discuss TRA options with DUSD(S&T) as early as possible*
- One approach has been
 - Component S&T Executive should prepare an interim TRA that assesses all potential CTEs in order to
 - Document the current state of maturity and path forward for probable CTEs
 - Provide an early indication of challenges and risks
 - MDA should
 - Require an updated TRA within 3 to 6 months in ADM language
 - Give the program provisional Milestone B approval pending an evaluation of the final TRA



The key points are:

- The Components should provide as much pertinent information as possible.
- DUSD(S&T) should develop its recommendations based on the data available.
- If there is a decision to proceed, DUSD(S&T) should recommend ADM language requiring another review in the near term when additional data are available.
- The MDA should reserve the right to stop the program at that time.

CTEs May Not Be Associated with a Key Performance Parameter (1 of 2)



Stryker Nuclear Biological Chemical Reconnaissance Vehicle (NBCRV)

- KPPs concerned interoperability and transportability of the NBCRV itself
- NBCRV ORD called for integration of a standoff chemical agent detector
 - The mission essential function is to detect and classify
 - The Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD) is a passive infrared detection system that detects the presence or absence of chemical warfare agents planned for the NBCRV
- JSLSCAD was appropriately identified as a CTE



Criticality to the program test is: “Does the technology directly impact an *operational requirement*?”

The important thing is to examine all of the operational requirements and not limit the search to the key performance parameters.

CTEs May Not Be Associated with a Key Performance Parameter (2 of 2)

Sensor Example

- Two technologies were inappropriately excluded
 - Hyperspectral Imagery: New technology but not required to meet KPPs
 - Aided Target Recognition (ATR) Algorithms: Used to support throughput of SAR Imagery, not required to meet KPPs



Enabling technologies should not be excluded from being CTEs

Need to have these things to meet operational requirements. They are critical and they are very hard.

A CTE May Be In Another Program



Ground Vehicle Example

- A vehicle mounted, on the move, chemical agent detector was identified as a CTE
 - It impacted an operational requirement *and*
 - It was new
- The proposed solution was a passive infrared detection system that detects the presence or absence of chemical warfare agents was an independent program initiated in September 1996 under the Joint Program Office for Chemical, Biological, Radiological, and Nuclear Defense



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When a CTE is in another program, the program doing the TRA needs to assess the TRL based on its own requirements. For example, the FCS TRA assessed JTRS with respect to its own (FCS) requirements. JTRS assessed its critical technologies based on the JTRS requirements.

Modified COTS Product May Be a CTE

Business Information Technology System Example



- TRA claimed no CTEs; submitted an information paper arguing that a TRA was not necessary
- Industry leading software package selected as the COTS basis for the IT System
- Software package being used in other Government agencies as well as in the private sector
 - *This would seem to imply that the environment is not new or novel*
- The information paper went on to say “It is the intent of DoD to use the software package without modification **to the maximum extent possible**”
 - *There is a clear basis for questioning if there is a CTE. A dimension of “new or novel” is whether the technology has been modified. The software package certainly impacts an operational requirement.*

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This has been a common situation. Programs have claimed that if its CTEs are being used elsewhere in Government, a TRA is not necessary because all of the TRLs are 9. All programs are required to do a TRA.

CTE Coordination and Data Collection



- PM submits list to the Component S&T Executive and requests a TRA
- S&T Executive may add CTEs if it is felt that special attention is warranted
- PM collects evidence of CTE maturity
 - Ongoing process throughout CTE identification
 - May include
 - Component and subsystem test descriptions
 - Analyses
 - Environments
 - Results

Keep DUSD(S&T) informed; may suggest additional CTEs

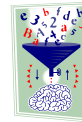
33

Remember, the Component S&T Executive (or his/her designated agent) is the one who coordinates on the CTE list.

Either the PM or the Component S&T Executive may add CTEs over and above those recommended by the independent review team, if they feel that special attention is warranted. ODUSD(S&T) may suggest additional CTEs, it is a good idea to accommodate such a request.

PM
Responsibility
To Provide

Independent Review Team Information Needs (1 of 3)



- **Program overview to set the foundation for the CTE assessments**
 - Concept of operations
 - Program master schedule
 - Identify significant milestones, items on the critical path and status progress
 - Operational performance requirements
 - Highlight KPPs, in general, and those operational requirements that will be directly influenced by the CTEs to be assessed
 - Challenges associated with the CTEs to be assessed
 - Technology maturation roadmap
 - Highlight those maturation events that have been accomplished and those yet to occur
 - Overall system architecture
 - Highlights the CTE system / subsystem elements that will be assessed

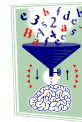
34

This reflects things that the PM needs to tell the independent review team.

The independent review team needs a good handle on the operational requirements, what the PM thinks the challenges are with the CTEs, and the events that will occur to demonstrate how the CTEs will mature.

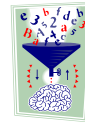
PM
Responsibility
To Provide

Independent Review Team Information Needs (2 of 3)



- **Introduction to the subsystems containing the CTEs**
 - Technical description of the subsystem, to include physical architecture, highlighting CTEs (components and/or packaging), explaining why other technologies within subsystem are non-critical, and differentiating subsystem and elements from that of potentially similar designs (i.e., highlight any uniqueness)
 - Description of the subsystem's intended function in the design
 - Significance of the CTEs relative to the subsystem
 - Significance of the subsystem relative to the system overall design
 - Traceability of the subsystem relative to the applicable operational requirements and state whether impact to a KPP
 - Schedule for the design and integration of the subsystem, clearly identifying critical path events and, if relevant, expectation/deliveries from suppliers
 - Block diagram and risk assessment for the subsystem
 - Roadmap of on-going and planned maturation activities and how these events can influence the master design schedule

This represents a data intensive description of the components of WBS or architecture.

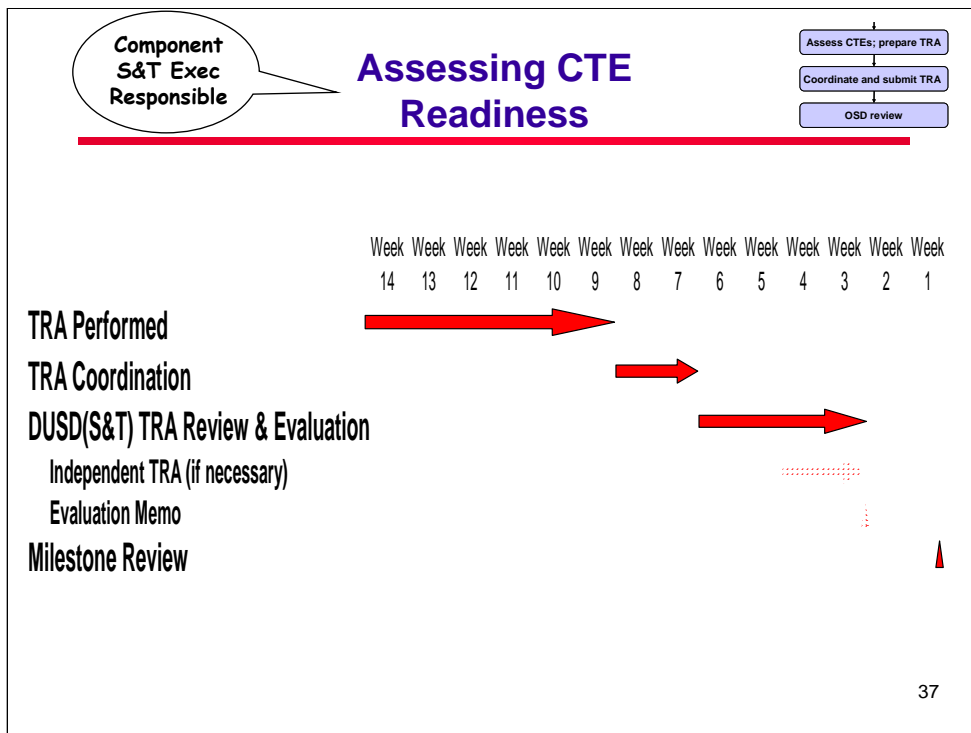


- **Status of CTE**
 - **Accomplishments that directly reflect CTE maturation**
 - Use TRL rating factors as a guideline
 - State quantitative facts where possible in order to temper and legitimize significance of the technology maturation accomplishments
 - Describe the measurement environment and methodology used
 - Identify who witnessed the subsystem/technology maturation accomplishments
 - **Tangible evidence of CTE maturation accomplishments (e.g., hardware, pictures, displays, technical papers, reports, etc.)**
 - Clearly state what is and is not represented by the evidence
 - **Relevant CTE maturation leveraged from other programs**
 - Clearly state any differences between this program and the leveraged program to appreciate significance of maturation events
 - **Significant maturation events that fall short or have not been accomplished**

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The independent review team will be looking for data and graphs to support the assessment in different environments.

The maturation process is not completely smooth. There will be interest in events where the technology did not perform as expected or desired.



Upper right hand corner indicates the portions of the process we are about to discuss. Note there are three blocks, corresponding to the top three major rows in the timeline. Subsequent slides discuss each row. Last row is just the milestone review itself.

While the Component S&T has overall responsibility for the top two rows, as you will see, others have key roles.

Such a schedule generally applies to all milestones. Key is to get the results to DUSD(S&T) early enough for the review and evaluation.

TRL Overview

- **Measures technology maturity**
- **Indicates what has been accomplished in the development of a technology**
 - Theory, laboratory, field
 - Relevant environment, operational environment
 - Subscale, full scale
 - Breadboard, brassboard, prototype
 - Reduced performance, full performance
- **Does not indicate that the technology is right for the job or that application of the technology will result in successful development of the system**

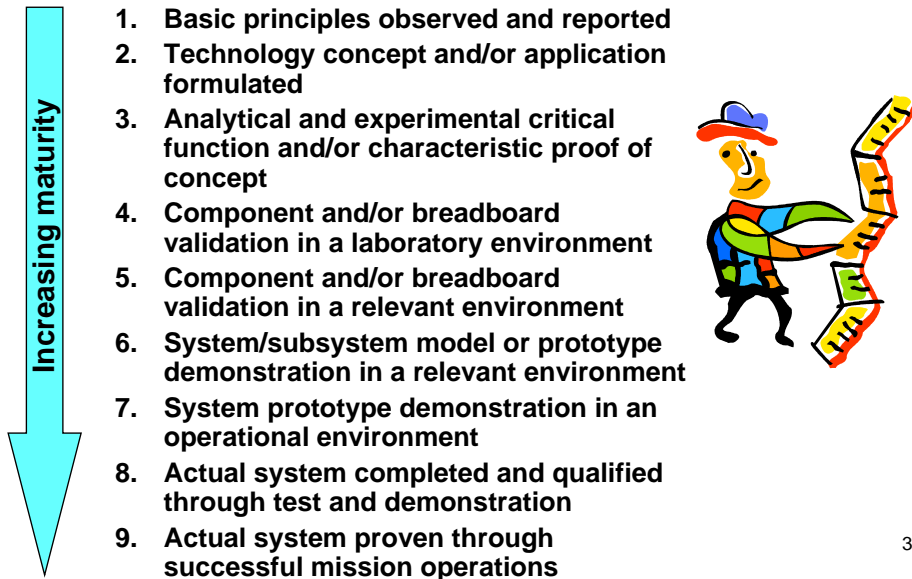


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Concept was pioneered by NASA.

The TRL is not a predictor of where you are going to be. It does not comment on whether SE has picked the right design or the right technologies.

Hardware TRLs



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TRLs 1 thru 3 are in the tech base, pre MS A.

TRL 4 or greater is the preferred maturity at MS A.

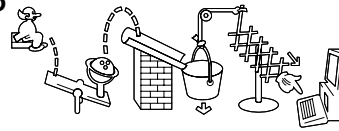
TRL 6 is required for MS B.

Technologies should be TRL 7 or greater at MS C.

TRL 4 Hardware

Minimum Maturity at Milestone A

- **Definition:** Component and/or breadboard validation in a laboratory environment.
- **Description:** Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory.
- **Supporting Information:** System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.

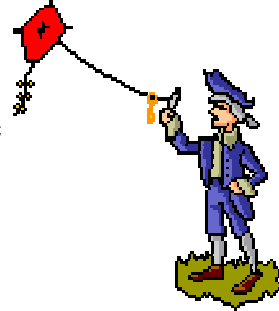


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This is relatively low fidelity, based on lab tests or bench tests, and then your estimation of how the system is going to work. However, it is a real scientific statement of what has been accomplished at the bread board/component/laboratory environment.

TRL 5 Hardware

- **Definition:** Component and/or breadboard validation in a relevant environment.
- **Description:** Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include “high-fidelity” laboratory integration of components.
- **Supporting Information:** Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the “relevant environment” differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?



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A relevant environment example may be the electromagnetic environment or conditions.

TRL 6 Hardware

Minimum Maturity at Milestone B

- **Definition:** System/subsystem model or prototype demonstration in a relevant environment.
- **Description:** Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.



- **Supporting Information:** Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?

The level of maturity is achieved after you have tested the system or subsystem in a relevant environment. You should be testing something very close to its final configuration.

TRL 7 Hardware

Minimum Maturity at Milestone C

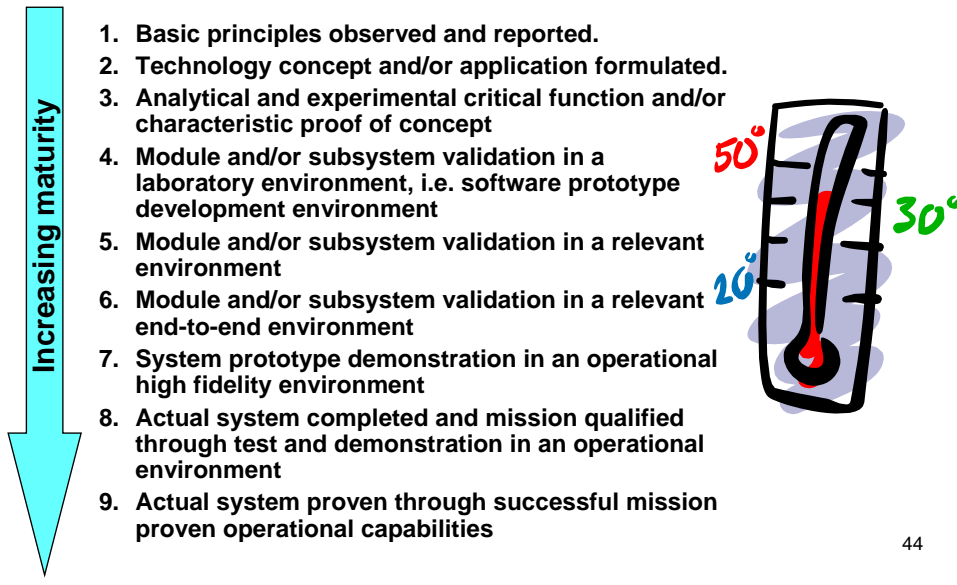
- **Definition:** System prototype demonstration in an operational environment.
- **Description:** Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space). Examples include testing the prototype in a test bed aircraft.
- **Supporting Information:** Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?



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TRL 7 is the preferred maturity at MS B, based on GAO's review of industry best practices.

Software TRLs



Hardware technology may include software that executes on the hardware if (1) the software is not being developed or modified as part of the acquisition or (2) the software is not the reason for placing the element on the CTE list. Therefore a tactical subsystem with imbedded software may be identified as a CTE and its maturity may be assessed using only the hardware TRLs.

Generally, the software TRLs are analogous to the hardware TRLs. The terminology changes. The word "module and/or subsystem" replaces "component and/or bread board."

Note: End-to-end environment includes the data and the sequencing of transactions in that environment.

TRL 4 Software

Minimum Maturity at Milestone A

- **Definition:** Module and/or subsystem validation in a laboratory environment (i.e., software prototype development environment).
- **Description:** Basic software components are integrated to establish that they will work together. They are relatively primitive with regard to efficiency and robustness compared with the eventual system. Architecture development initiated to include interoperability, reliability, maintainability, extensibility, scalability, and security issues. Emulation with current/legacy elements as appropriate. Prototypes developed to demonstrate different aspects of eventual system.
- **Supporting Information:** Advanced technology development, stand-alone prototype solving a synthetic full-scale problem, or standalone prototype processing fully representative data sets.



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The software prototype is analogous to the bench test in the hardware world.

TRL 5 Software

- **Definition:** Module and/or subsystem validation in a relevant environment.
- **Description:** Level at which software technology is ready to start integration with existing systems. The prototype implementations conform to target environment/interfaces. Experiments with realistic problems. Simulated interfaces to existing systems. System software architecture established. Algorithms run on a processor(s) with characteristics expected in the operational environment.



- **Supporting Information:** System architecture diagram around technology element with critical performance requirements defined. Processor selection analysis, Simulation/Stimulation (Sim/Stim) Laboratory buildup plan. Software placed under configuration management. COTS/GOTS in the system software architecture are identified.

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A relevant environment might be a COTS application that you build simulators around to represent what you think the subsystem will look like.

TRL 6 Software

Minimum Maturity at Milestone B



- **Definition:** Module and/or subsystem validation in a relevant end-to-end environment.
- **Description:** Level at which the engineering feasibility of a software technology is demonstrated. This level extends to laboratory prototype implementations on full-scale realistic problems in which the software technology is partially integrated with existing hardware/software systems.
- **Supporting Information:** Results from laboratory testing of a prototype package that is near the desired configuration in terms of performance, including physical, logical, data, and security interfaces. Comparisons between tested environment and operational environment analytically understood. Analysis and test measurements quantifying contribution to system-wide requirements such as throughput, scalability, and reliability. Analysis of human-computer (user environment) begun.

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A SW business system is often not designed until after MS B. If there are n different competitors, then there must be n assessments. To achieve this TRL must demonstrate maturity in the lab that is doing the development, i.e., must demonstrate inhouse maturity (unless there is a subcontract).

Another possibility is to perform the TRA as soon as possible after the Acquisition Decision Memorandum, preferably giving the program only limited authority to proceed until after the TRA is approved.

TRL 7 Software Minimum Maturity at Milestone C

- **Definition:** System prototype demonstration in an operational high-fidelity environment.
- **Description:** Level at which the program feasibility of a software technology is demonstrated. This level extends to operational environment prototype implementations where critical technical risk functionality is available for demonstration and a test in which the software technology is well integrated with operational hardware/software systems.
- **Supporting Information:** Critical technological properties are measured against requirements in a simulated operational environment.



MS B Requirement: Demonstration or Validation in a Relevant Environment (TRL 6)



A *relevant environment* for the demonstration of a technology is a set of test conditions that provide confidence that skillful application of that technology to an item (component, subsystem, or system) will support the required (threshold) functionality of that item across the full spectrum of required operational employments.

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Example: Software components demonstrated in narrow regime (e.g., logistics). Need to have arguments and tests to prove that it will work in other environments as well.

Demonstration or Validation of a Technology in a Relevant Environment

- Requires successful trial testing that either:
 - shows that the technology satisfies functional need across the full spectrum of operational employments, or
 - shows that the technology satisfies the functional need for some important operational employment and uses accepted techniques to extend confidence over all required operational employments.



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Need to have a trial test directly, or if through modeling and simulation, need enough data to support that it applies across all employments.

TRA Performed

- Program responsible for funding, **BUT** most of the work has already been done
- Independent team trained and convened by the Component S&T Executive to
 - Make the assessments
 - Write the report
- Multiple TRAs should be conducted if multiple systems still in competition



Contact DUSD(S&T) with any issues (e.g., CTE uncertainty) early in the process

[Hardware
assessment
criteria](#)

See additional hardware examples
in Section C.2 of the Deskbook

[Software
assessment
criteria](#)

See additional software examples
in Section C.3 of the Deskbook

[Manufacturing
assessment
criteria](#)

See additional manufacturing examples
in Section C.4 of the Deskbook

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The earlier DUSD(S&T) involved, the better.

The Component S&T Executive should not ask the PM to do the TRA. “The student should not grade his own homework.” This does not meet the independence criterion for a TRA. The PM should supply the data for the independent review team assessment.

Best Practices for a Preliminary TRA at Milestone A (Only Applies to Ships)

Example

- **Use the TRA to identify areas for management focus**
 - Create critical technology IPTs
- **No contract award yet**
 - Update the TRA after a selection decision
- **No TRL requirements**
 - TRL of 3 or lower implies higher technology risk
 - Technology Development Phase generally mature technology from 4 to 6
 - Use Technology Transition Agreements



Non Complex Technology Is Unacceptable Rationale for TRL 6 or Higher

Example



- **Sub-system identified as CTE**
 - There is not a similar or existing prototype that has demonstrated an ability to perform the sub-system's mission from the example platform
- **Inappropriately assessed at TRL 6**
 - Although the sub system is in concept design, its low technical complexity will allow use of known and proven fabrication methods and materials

**Demonstration of a prototype in a relevant environment is
pre-condition for TRL 6**

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Just because a technology looks easy to implement, you still must demonstrate it in a relevant environment for it to be TRL 6.

System Level Demonstration Required for TRL 7 or Higher



Software Intensive System Example

- TRA 1 inappropriately identified two CTEs as TRL 7 and two as TRL 8
- The rationale for the TRL scores is that the systems being scored are currently in operational use and have already been through the acquisition process. Integration into a common environment is the major area to be addressed for each critical technology. The panels approached the integration issue from the standpoint that integration will occur during System Development and Demonstration (SDD), and therefore the TRL score is based on the individual critical technology.
- CTEs should have been assessed to be TRL 6

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Without the integration, the technologies haven't been demonstrated in an operational environment.

TRL 7 Requires Demonstration of a System Across All Operational Environments



Software Intensive System Example

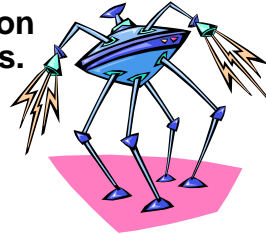
- **TRA stated**
 - **For the purposes of this TRA, if a critical technology has been implemented in the operational baseline in a limited basis (e.g., within a single mission application), it is considered an actual system prototype in an operational environment.**
- **Many CTEs were inappropriately assessed as TRL 7**
- **TRL 7 requires testing across all potential operational environments or basis for extending limited tests to the full spectrum of operational environments**

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Include Sufficient Data in the TRA to Evaluate the TRL (hardware 1 of 3)

Vehicle Example

- The Sub-System X was identified as a CTE for a Milestone C TRA
- No specifics were provided in the TRA on how Sub-System X met its requirements. The TRA only included:
 - Testing underway ...
 - Scope of test is ...
 - Rounds fired to date are ...
 - Sub-System X has been incorporated on other platforms
 - Integration of Sub-System X into the vehicle has technical challenges
 - As part of risk mitigation ...

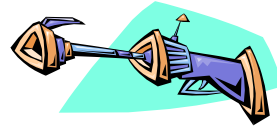


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A reviewer must point out areas where data are lacking.

Include Sufficient Data in the TRA to Evaluate the TRL (hardware 2 of 3)

- **TRA cover letter actually provided more specifics**
 - While Sub-System X testing has shown that it meets its performance requirements the reliability of a component needs improving. The PM has identified a contractor who has considerable experience in the design, development and manufacture of these components. Their assessment is that incremental improvements in design of Sub-System X are possible through modest design enhancements.
- **TRA 7 was assigned**

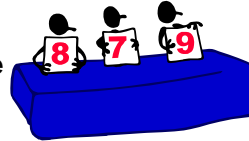


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TRA preparer must include data used and references for those data.

Include Sufficient Data in the TRA to Evaluate the TRL (hardware 3 of 3)

- **Observations**
 - The TRA should identify the quantitative requirements specific to the CTE
 - The TRA should provide the results of tests relative to those requirements
 - If the test results are not available, TRL 5 is the maximum achievable
 - The TRL 7 in this example was inappropriate
 - Milestone C is not the time for redesign
 - A Technology Maturation Plan should have been requested
- **Because of pressure to field, the ADM authorized procurement of test vehicles and long lead items for additional vehicles. Further procurement was contingent on successful demonstration of reliability growth.**



Include Sufficient Data in the TRA to Evaluate the TRL (software)

- While a lot of work went into the TRA, it was very soft on showing quantitative requirements for the CTEs
- Excerpts from the DUSD(S&T) evaluation letter
 - COTS products are generally rated as being TRL 5 if they have similar examples of use in industry
 - TRL ratings of 6 or higher must be based upon actual experience with those products by the receiving organization(s) in an environment close to that intended for the deployed system
 - The TRA does not provide sufficient detail on how the selected products fulfill functional expectations, and how the results of the pilot efforts justify the proposed TRL ratings
 - Two critical technologies were used in pilots but no results are cited
 - For several technologies, the pilot results were described simply as no problems noted during the pilot efforts
 - Four of the critical technologies were not piloted



Beware of TRLs Driven by Non-Technological Considerations at MS C (1 of 4)



Ground Vehicle Example

- **CTE identified**
 - Detection System X, a passive infrared detection system that detects the presence or absence of chemical warfare agents, was identified as a CTE
 - The Detection System X was to be provided by another independent program



Beware of TRLs Driven by Non-Technological Considerations at MS C (2 of 4)

- **Background**

- Initial plans called for the use of Detection System Y, a different infrared detection system. Because of obsolescence issues, the requirement became specified as “performs as well as Detection System Y or better” and Detection System X was selected for integration.
- While Detection System X was not meeting its own requirements, the program was restructured such that Increment I addressed the example ground vehicle needs only.



Beware of TRLs Driven by Non-Technological Considerations at MS C (3 of 4)

- **Component assessment**
 - Detection System X is not meeting all of its revised requirements
 - Detection System X provides better operational capability than Detection System Y. Its performance is better than not having it and having it does provide a militarily useful increment of capability.
 - *Enough Detection System Xs have been built to equip the entire example vehicle fleet*
 - A TRL of 7 was assigned by the Component S&T Executive
- **ADM**
 - The ADM directed the development an acquisition strategy and plan to upgrade Detection System X for integration into the example vehicle and to assess changes to force structure and tactics resulting from current limited sensor performance



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The TRL 7 assessment was for the example ground vehicle purposes only. There was no separate TRA for Detection System X.

Beware of TRLs Driven by Non-Technological Considerations at MS C (4 of 4)

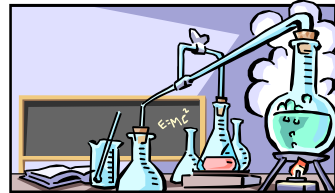
- **Reviewer Considerations**
 - Detection System X TRL could be no higher than 6 relative to the example vehicle requirements
 - It was not demonstrated in an operational environment, it is unknown whether it was even demonstrated in a relevant environment
 - But
 - Detection System X was produced and fielded
 - Detection System X provided a militarily useful capability increment
 - The pressure / decision to field the already built units in effect waived the example vehicle requirements, making a TRL 7 technically correct



Contents

20%	1.0 Purpose of This Document	
	2.0 Program Overview	
	2.1 Program Objective	
	2.2 Program Description	
80%	2.3 System Description	
	3.0 Technology Readiness Assessment	
	3.1 Process Description	
	3.2 Critical Technologies	
	3.3 Assessment of Maturity	
	3.3.1 First CTE or Category of Technology	
	3.3.2 Next CTE or Category of Technology	
	3.4 Summary of TRLs by Technology	
	4.0 Conclusion	

Focus is not
programmatic



TRA is a technical report with references

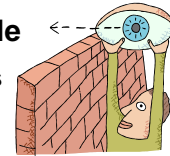
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The assessment itself is the meat of the document. The process through which the assessment is made should be a very small portion. This is one of the few technical documents that go to the Milestone Decision Authority.

TRA Section 3.1 Should Identify Independent Review Team Members

Operational Planning System Example

The independent TRA team is composed of system engineers from an FFRDC, and the University of Goodness. The four principals leading the assessment are:



- Mr. X, FFRDC Corporation. Mr. X has 26 years of computer systems experience, and 16 years experience in the environment. He holds a Bachelors of Arts in Quantitative Methods from the University of X and a Master of Science in Information Systems from the School of Engineering, University X.
- Mr. Y, FFRDC Corporation. Mr. Y has 24 years of computer systems experience, and 9 years experience in the environment. He holds a Bachelors of Science in Computer Science from the University of Y and a Master of Science in Management Information Systems from the University of Y.
- Mr. Z, FFRDC Corporation, Mr. Z has 7 years of computer systems experience. He holds a Bachelors and Master of Science in Electrical Engineering and Computer Science from the Institute of Z.
- Dr. A, University of Goodness, Senior Technology Consultant, College of Information Science and Technology.

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The TRA should provide the names of the independent review team. A brief bio should be sufficient to show their technical qualifications.

TRAs Should Not Include Pleas for a Favorable Programmatic Decision (1 of 2)



- Example 1
 - “... as part of a risk mitigation plan, eight prototype vehicles with the System are undergoing testing. *Based on the results to date, the System is considered mature enough to enter low rate production.*”
- Example 2
 - “...*the maturity of the critical technologies along with the associated risk mitigation approaches support entry into SDD ...*”

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The TRA should show what has happened to date. It should not contain opinions or legal arguments.

TRAs Should Not Include Pleas for a Favorable Programmatic Decision (2 of 2)



- Example 3
 - “The Example 3 Product Manager identified two critical Technologies for the readiness of the program to enter the Design and Development Contract. *It is the opinion of the Example 3 Product Office that these two critical technologies have matured to a TRL level sufficient for entry into the SDD contract. These two technologies will have matured to a TRL level sufficient to enter LRIP far ahead of schedule.*”
 - “Evolution of a system’s T/R module offers the best available alternative for this example to meet T/R module requirements in SDD. This effort is imperative to the success of SDD and is *true ‘risk reduction’*”

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It is not appropriate to argue that risk reduction is underway is a basis for a higher TRL.

Title 10 requirement for certification

- H.R. 1815 Sect 801 §2366a. (signed Jan 6, 2006):
Major defense acquisition programs: certification required before Milestone B or Key Decision Point B approval:
 - (a) **CERTIFICATION.** *A major defense acquisition program may not receive Milestone B approval, or Key Decision Point B approval in the case of a space program, until the milestone decision authority certifies that –*
 - (1) *the technology in the program has been demonstrated in a relevant environment;*
 - ...
 - (7) *The program complies with all relevant policies, regulations and directives of the Department of Defense*

Certification Submitted Quarterly in the SARs

Component TRA Coordination

- Identified CTEs and assessed TRL
 - Component TRA approval is an agreement on its accuracy only
- Maturity requirements:
 - Subsystem demonstrated in a relevant environment (TRL 6) for MS B;
 - Prototype (TRL 7) or actual system for manufacturing CTEs (TRL 8) demonstrated in an operational environment for MS C
- ~~Three options if a technology is immature~~
 - ~~Request a delay for technology maturation until all CTEs are at a minimum TRL 6~~
 - ~~Utilize mature technologies; or,~~
 - ~~As a last resort, use immature technologies into the program. Review and submit a technology maturation plan with the TRA.~~

**Waivers will not usually be issued:
Technology Maturation Plans no
longer a substitute for Readiness**



Acquisition Executive submits the TRA to DUSD(S&T)

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Approval of the accuracy does not necessarily signify a decision to go ahead. The Component S&T Executive may recommend any of the three options to the Component Acquisition Executive.

We have labeled the go ahead as planned with immature technologies option as the “last resort” because of the nature of the SDD process. It is highly schedule driven. The technology maturation process is event driven, as is the systems engineering process. Inclusion of two event driven processes in a schedule driven environment is cause for concern. So, in our opinion, the “last resort” is really a best practice.

Unfortunately, this last resort is becoming standard procedure in practice. There is a great deal of pressure to initiate programs – that is the point where funding normally increases substantially. Some have suggested that 6.2 and 6.3 funding limitations have prevented programs from reaching TRL 6 before MS B. On the other hand, there are programs that remain in the tech base for years. In some cases, an influential champion makes the difference.

DUSD(S&T) TRA Review

- **Results of initial review**
 - Concur
 - Request revisions
- **Results of final review**
 - Concur
 - Concur with reservations
 - Perform independent technical assessment



DUSD(S&T) informs Milestone Decision Authority of the results

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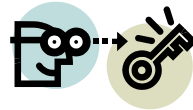
There is an iterative process between the initial review and the final review. Its scope and nature depend on the specific situation.

DUSD(S&T) reservations typically become language incorporated into the Acquisition Decision Memorandum. Such language may call for an updated TRA, a special technology IPT, etc.

To date, there have been no independent technical assessments.

DUSD(S&T) Review Should Evaluate More Than TRLs (1 of 2)

- The TRA itself is a technical report ... *but* ...
 - Some judgment required to assess whether TRLs have been properly assigned
 - Factoring the TRA into a programmatic decision requires a great deal more judgment
- Treat the TRA as an opportunity to gain insight on how the technology maturity affects programmatic risk
 - Coordinate with the review of the Systems Engineering Plan
 - Use this insight in recommending whether a delayed entry into the next phase should be considered



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These insights should be passed on to the Milestone Decision Authority so they may be incorporated into the decision process. Perhaps Acquisition Decision Memorandum language can allay concerns.

DUSD(S&T) Review Should Evaluate More Than TRLs (2 of 2)

An Example in Hindsight



- The TRA was a well prepared, substantial document
- TRA excerpts:
 - “... the basic characteristics outlined in the KPPs were evaluated using various existing and proposed R&D hardware and software programs...”
 - “... there was no system and subsystem models, or prototypes available to be evaluated...”
 - “...none of the R&D hardware/software used in this assessment will be used directly in the system prototype...”
- 11 CTEs identified
 - 10 assessed to be TRL 5
 - 1 assessed to be TRL 4
- *Three years later, the program is in trouble, unable to meet requirements*

Outline

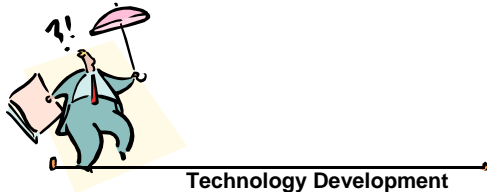
- Introduction
- Overview of Technology Considerations During Systems Acquisition
- The TRA Process
 - Identifying Critical Technology Elements (CTEs)
 - Assessing CTE Readiness
- **Technology Maturation**
- References and Resources

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This section of the briefing focuses on what happens if the technology is immature at Milestone B although some of it is also applicable to all CTEs.

Technology Maturation Policy is Unambiguous

“The project shall exit Technology Development when an affordable increment of militarily-useful capability has been identified, the technology increment has been demonstrated in a relevant environment, and a system can be developed and produced within a short timeframe (normally less than five years); or when the MDA decides to terminate the effort. A Milestone B decision marks the completion of Technology Development.” (DoDI 5000.2, paragraph 3.6.7)



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The policy is absolutely clear. A Technology Development Phase exit criterion – or depending on how you look at it- a System Development and Demonstration Phase entry criterion is: the critical technologies must have been demonstrated in a relevant environment.

Technology Maturation Policy (continued)

“The management and mitigation of technology risk, which allows less costly and less time-consuming systems development, is a crucial part of overall program management and is especially relevant to meeting cost and schedule goals.



Objective assessment of technology maturity and risk shall be a routine aspect of DoD acquisition. Technology developed in S&T or procured from industry or other sources shall have been demonstrated in a relevant environment or, preferably, in an operational environment to be considered mature enough to use for product development in systems integration. Technology readiness assessments, and where necessary, independent assessments, shall be conducted.

If technology is not mature, the DoD Component shall use alternative technology that is mature and that can meet the user's needs.” (DoDI 5000.2, paragraph 3.7.2.2)

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The policy goes on to say that:

1. Technology risks must be managed and mitigated and
2. If the technology is not mature enough (i.e., it has not met the SDD entrance criterion) use something else that is mature

Guidance for Immature Technologies



If the system does not meet pre-defined Technology Readiness Level scores, then a Critical Technology Element maturation plan is identified. This plan explains in detail how the Technology Readiness Level will be reached prior to the next milestone decision date or relevant decision point.” (Defense Acquisition Guidebook Section 4.3.2.4.3. Technology Readiness Assessment (TRA))

- TRL 6 required at MS B.
- TRL 7 required at MS C; TRL 8 for manufacturing CTEs.

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The Defense Acquisition Guidebook acknowledges that there may be exceptions and recommends that there be a CTE maturation plan for immature technologies.

Two key points to make:

1. This is a very important best practice and we recommend that there be a CTE maturation plan for every CTE, regardless of its maturity at the Milestone. After all, these technologies are critical, they effect program risk, and they will eventually have to mature to TRL 9.
2. There is a debate on how strictly the policy should be enforced.
 - A parallel can be drawn to the Systems Engineering Plan (SEP) required at all milestones by at USD(AT&L) policy memo. OSD provides detailed comments (usually critical) on these plans. An explicit threat to stop programs if the SEP is not adequate. This is a relatively strict enforcement of policy.
 - The other side of the debate says the programs know what they are doing, they'll get the technologies into the system on cost and on schedule. That is reminiscent of the George Strait song “Ocean Front Property in Arizona”

Programs Do Not Uniformly Understand Technology Maturation Policy

Example System

- System will include technologies undergoing continuous maturation until the Critical Design Review
- This approach is consistent with the emerging DoD Acquisition guidelines and will be typical of future programs in which substantial gains in capability are sought
- The TRA plays a key role in the acquisition process by documenting the current state of maturity and path forward for each of the critical technologies to enable the success of this approach
- By clearly identifying the challenges and risks for the critical technologies at this point in the program, overall program risk is reduced and can be managed with the SDD phase

This approach is not consistent with DoDI 5000.2

TRA helps ensure success by potentially preventing programs from moving forward with immature technologies

How can identification alone ensure that risks can be managed or reduced?

This slide lend credence to the strict enforcement side of the debate. All programs do not have a good handle on acquisition policy.

Further evidence of this can be seen with some statistics about the SEPs from one Service. The SEP is plan for the program's technical development.

- 40% of programs did not define requirements below those stated in the ICD/CDD. One program said "we don't have any requirements."
- 73% of programs didn't have or didn't know their processes
- 45% of programs didn't know their risks
- 45% of programs didn't have entry and exit criteria for design reviews

Technology Maturation Documents

- **Technology Development Strategy / Acquisition Strategy**
 - Defines process
- **MOA/MOUs**
 - Articulates external dependencies on other programs
- **Technology Transition Agreements**
 - Articulates external program dependencies on technology base programs
 - Establishes specific technologies, technology demonstration events, and exit criteria for the program
- **Technology Maturation Plans**
 - Defines how CTEs will be matured in conjunction with the Integrated Master Schedule
- **Risk Mitigation Plans**
 - Identifies risks associated with CTEs and actions for mitigating them



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These documents have a bearing on technology maturity

- We have already discussed the TDS. It is applicable at MS A. The TDS evolves into the acquisition strategy at MS B, where it incorporates other subjects e.g. risk management, T&E, systems engineering, etc.
- MOAs and MOUs mostly occur in Technology Development Phase
- TTAs with laboratories usually occur during Technology Development
- TMPs are done hand in hand with the TRAs
- RMPs link closely with the TMPs and become the basis for tracking CTE maturity in the systems engineering technical reviews. This reinforces the point made earlier about the need for every CTE to be tracked in the risk database.

PM
Responsible

Technology Maturation Plan Outline

- Title
- Statement of the problem
 - Describe the technology and its maturity status.
 - Say how this technology would be used in the system.
- Solution options
 - Benefits of using the preferred technology
 - Fall-back options and the consequences of each
- Maturation program plan with schedule
 - Describe key activities for preferred technology
 - Describe preparations for using an alternative
 - Show the latest time for choosing an alternative
- Specific actions to be taken (what will be done and by whom)
 - What prototypes or EMDs will be built.
 - What tests will be run
 - How the test environment relates to the operational environment
 - What threshold performance must be met
 - What TRL will be achieved
- Status of funding to perform this technology maturation

Status monitored at technical reviews and OIPT meetings.

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These are the best practice contents for a TMP. The plan should be thorough. Doing this should not be a burden. If you can't document the process, you don't have a process.

Obviously what you see here looks like a risk mitigation plan. The reason is that the risk mitigation plan was the basis for developing this best practice. Recognize however that the risk mitigation plan covers more than technology risks.

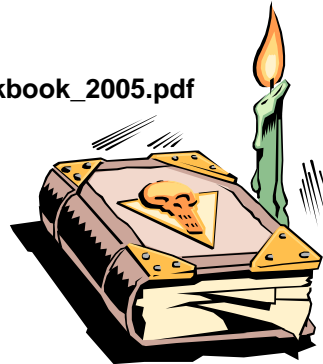
Of course, the PM must be the one to prepare the TMP. It is a best practice to have it reviewed by the independent review team.

Outline

- Introduction
- Overview of Technology Considerations During Systems Acquisition
- The TRA Process
 - Identifying Critical Technology Elements (CTEs)
 - Assessing CTE Readiness
- Technology Maturation
- References and Resources

References and Resources

- **Defense Acquisition Resource Center**
<http://akss.dau.mil/darc/darc.html>
 - DoD Directive 5000.1 (DoDD 5000.1), *The Defense Acquisition System*, dated May 12, 2003
 - DoD Instruction 5000.2 (DoDI 5000.2), *Operation of the Defense Acquisition System*, dated May 12, 2003
 - *Defense Acquisition Guidebook*
- **TRA Deskbook**
http://www.defenselink.mil/ddre/doc/tra_deskbook_2005.pdf
- **DDR&E**
 - Mr. Jack Taylor jack.taylor@osd.mil
- **Institute for Defense Analyses**
 - Dr. Cynthia Dion-Schwarz cdion@ida.org
 - Dr. Jay Mandelbaum jmandelb@ida.org

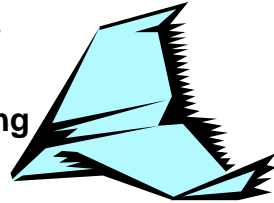




Hyperlinks

Example Questions to Help Identify CTEs for an Aircraft (Aerodynamic Configuration)

- Does the design incorporate a configuration that has not been used in flight?
- How similar is the configuration to that of aircraft that are successful?
- Does the configuration impose limitations on control authority, stability, structural rigidity, or strength?
- Is stability acceptable at high angles of attack?
- Is stability and control acceptable during configuration changes in flight?



Example Questions to Help Identify CTEs for a Networked Communication System

- **Do the requirements for throughput, data latency, security or reliability imply that a new or novel technology is required?**
- **Have the network routers been used before within the required performance envelope?**
- **Are new or novel media access control, coding, or routing algorithms needed?**
- **Is the multiplexing schema new?**
- **Is the topology (logical and hardware) new?**
- **Do the peak and average data rates require hardware or algorithms in the system?**



Example Questions to Help Identify CTEs for a Manufacturing Technology

- Has the manufacturing technology been successfully integrated into a product?
- Is the industrial base capable of design, development, production, maintenance and support, and disposal of the system?
- Is the intended design producible?
- Have the materials been characterized in a manufacturing environment?
- Are the materials available to meet quantity and schedule demands?
- Are the design-to-cost goals achievable?
- Are the key manufacturing processes characterized, capable, and controllable with respect to achieving the performance requirements?



Attainment of Technology Readiness for Hardware CTEs

Accomplishment	TRL Supported								
	1	2	3	4	5	6	7	8	9
Discovery of physical or mathematical principle	X								
Characterization of the principle	X								
Application envisioned and described		X							
Concept of application analyzed		X							
Critical functionality empirically confirmed			X						
Proof of concept demonstrated in laboratory			X						
Scale-up or other extension as needed by concept			X	X					
Breadboard or component tested in laboratory				X					
Producibility and cost estimated				X	X				
Engineering Development Model (EDM) of component tested in laboratory				X					
EDM of component tested in relevant environment					X				
Prototype component integrated into a system EDM				X	X				
System EDM tested in simulated environment				X					
System tested in limited field experiments				X	X				
System tested in relevant environment						X			
System tested in operational environment							X		
Production system tested in operational environment								X	
Production system proven in mission operations									X

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Attainment of Technology Readiness for Software CTEs

Accomplishment	TRL Supported								
	1	2	3	4	5	6	7	8	9
Discovery of mathematical principle or algorithm	X								
Characterization of the principle	X								
Application envisioned and described		X							
Concept of application analyzed		X							
Critical functionality empirically confirmed and implemented software			X						
Proof of concept demonstrated in simulation			X						
Scale-up or other extension as needed by concept			X	X					
Component tested in simulation				X					
Producibility and cost estimated				X	X				
Software component tested in an integration laboratory				X					
Software component tested in a relevant environment					X				
Prototype component integrated into a system prototype				X	X				
System tested in a simulated environment				X					
System tested in a limited field experiments				X	X				
System tested in a relevant environment						X			
System tested in an operational environment							X		
Production system tested in an operational environment								X	
Production system proven in mission operations									X

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IT TRA Challenges

- TRA / TRL model derived for hardware-oriented systems
- Increasing number of defense acquisitions are software intensive
 - Few hardware or software elements can be singled out as CTEs
- New IT issues include
 - Interfaces
 - Throughput
 - Scalability
 - External dependencies
 - Process reengineering
 - Information assurance
- Environment / architecture plays a greater role



Software Intensive Systems Fall Into Five Broad Areas



- Information systems
- Business systems
- Networked communications systems
- Mission planning systems
- Embedded IT in tactical systems

Information Systems and Business Systems

- **Challenges**

- Large COTS applications
- Integration with legacy business applications
- Integration in final environment
- Data management
- End-to-end responsiveness
- Scalability



- **Recommendations**

- Start with lists of COTS products
 - Focus on critical applications used in a new or novel way
 - Use pilot experience to justify TRLs 6 and above
- Include integrating technologies where applicable
- Pay attention to DoD-unique environments
- Address system-level issues
 - Responsiveness, scalability, etc.

Networked Communications Systems

- **Challenges**
 - Services focus
 - Consolidation of user needs and anticipated growth
 - Managing standards
 - Technology rollover
 - Ability to provide services
 - May transcend individual products
- **Information assurance**
- **Recommendations**
 - Start with technologies that enable one or more services
 - Avoid process issues except where enabled by technology
 - Roll-out, configuration management
 - Establish TTAs where DoD needs not met by commercial technologies
 - E.g., mobile ad-hoc network protocols
 - Consider market capabilities as well as specific technologies



Mission Planning Systems

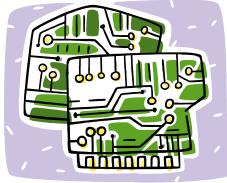
- **Challenges**
 - Reliance on external data sources
 - Mixed COTS/GOTS
 - Infrastructure upkeep and modernization
 - Technology turnover
 - Scalability and responsiveness
- **Recommendations**
 - Start with required functionality and supporting technologies
 - Identify critical data dependencies on external programs
 - Assess ability to succeed based upon total suite of data suppliers / users and infrastructure, not just application maturity



Embedded IT in Tactical Systems

- **Challenges**

- Lots of developed software
- Military-unique environments
 - Radiation hardened, shock / vibration, high reliability
- Military-unique functionality
 - IT as an enabler



- **Recommendations**

- Start with function domains or WBS
- IT typically not a CTE except where consolidated computing requirements are used
- For COTS, carefully examine relevant and operational environment success when rating technology readiness
- Do not address developer capabilities in assessing technology maturity

Attainment of Technology Readiness for Manufacturing CTEs (1 of 2)

Accomplishment	TRL supported		
	4	5	6
Emerging breadboard design options provide insight into potential manufacturing problems with the industrial base infrastructure (facilities & manpower), materials, methods, and measurement (inspection & test equipment).	X		
Breadboard design options provide insight needed to validate characteristics and potential geometries.		X	
Various strategies identified to mitigate technical and cost risk.		X	
Prototype brass board design has actual components, subsystems or systems that have associated manufacturing processes, materials and methods.			X
Preliminary assessment of manufacturing assembly sequences.			X
Industrial base infrastructure (facilities & manpower) capabilities along with measuring and test equipment initially evaluated.			X
Cost accounted for on high risk manufacturing areas and plans developed to mitigate risk.			X
Appropriate quality levels have been achieved.			X
Quality management model understood.			X

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Attainment of Technology Readiness for Manufacturing CTEs (2 of 2)

Accomplishment	TRL supported		
	7	8	9
Manufacturing processes, materials and assembly methods have been developed for a production environment; ideally in a pre-production facility or better.	X		
Design maturing; key materials and process characteristics have been identified, and planning is taking place for managing (process control as appropriate).	X		
Detailed manufacturing risk assessment covering industrial base infrastructure (facilities and manpower); materials (availability, producibility characteristics); methods (mature processes); measurement (inspection and test equipment); and costs.	X		
Quality management structure identified.	X		
Appropriate throughput levels have been achieved.	X		
Initial goals set for yields, quality, and reliability.	X		
Manufacturing processes, materials and assembly methods demonstrated on production representative articles with no known significant manufacturing risk.		X	
Yields, quality and reliability within 25% of goals.		X	
Design mature; process requirements proven and validated.		X	
Quality management structures in place.		X	
Manufacturing processes efficient and acceptable in factory environment.			X
Design producible; used to produce production articles for IOT&E and the field.			X
Design to cost goals met.			X

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